Development of a Spectrometer for Inelastic X-ray Measurements

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Abstract

Advanced Design Consulting, Inc. (ADC) in collaboration with the scientists at SRRC and BNL designed, fabricated and installed a spectrometer that is operating at the Spring-8 synchrotron in Japan as part of a dedicated inelastic beamline (BL12XU). The system is used for investigating electronic excitations with milli-electron volt resolution; therefore many of the specifications required high precision, and accuracy on the micron level. The 3-meter analyzer arm on the spectrometer needed to have an angular stability measured in arc seconds over a long range of travel, under vacuum conditions. In this paper measurement data from different parts of the spectrometer describing the precision, angular accuracy, and stability are summarized..

Keywords: Spectrometer, High Precision, Stability

1. Introduction

The IXS spectrometer, custom designed and built to accommodate a wide range of experimental requirements, was installed to the experimental hutch in April 2002. All performance indicators (sphere of confusion of all circles combined: ±7 μm; static stability: 10 μrad; angular stability of the analyzer against arm motion: 10 μrad) reach their design values. Using a bent Si (555) analyzer at near backscattering, we obtained the first loss spectrum on an Al foil (Figure2), which compares well with published data.

The spectrometer was designed for several types of inelastic X-ray measurements. Performing non-resonant, inelastic X-ray scattering, which directly measures the dynamical structure factor, $S(\boldsymbol{q},\omega)$, of the sample, will be the primary function. The scientific focus is to study the single-particle and collective electronic excitations in many-body systems. The incident table allows for reducing parasitic scattering, diagnostics, and attenuation of the highly monochromatic beam. In addition to the standard capability of orienting the sample, the spectrometer can be used with large magnets, furnaces, or a specially designed cryostat with a fine-positioning carrier, for measurement of samples in extreme environments. The spectrometer has the custom designed versatile capability of positioning a shielded detector in the backscattering geometry for use with various sample chambers, which will allow us to optimize the energy resolution.

The second purpose of the spectrometer is for Resonant Raman scattering, to capitalize on the large resonant enhancement of the inelastic scattering cross sections. The incident X-ray energy will be widely tunable to excite core electron absorption edges of samples ranging from the copper to vanadium. For large-q scattering, the instrument can also be used to do high- resolution Compton scattering.

2. Spectrometer Design

An overall view of the spectrometer is shown in Figure 1. In order to meet the design requirements for stability at a reasonable cost a set of off-the-shelf curved steel rails are used to support the free end of the analyzer arm. The rails and associated linear motion guides are standard products of THK.

Five 45° curved rail segments are used to support the free end of the arm over a useable arc of about 190°. While maintaining rail flatness is difficult over such a long structure this becomes especially problematic at the joints between guide rail segments. The linear motion guides are sufficiently long to support the arm as it traverses these joints provided that the slope, height and twist have been precisely controlled. Obviously a means for adjusting the position of the guide rail is required.

In order to provide precise positioning of the guide rail segments they are supported on a series of curved I-beams that are mounted to the floor. Support brackets are attached to the guide rail using the standard, threaded mounting points provided by THK. These brackets extend beyond the edges of the rail and contain the set-screws and clamping bolts that are used to make adjustments. To adjust the guide rails the clamping bolts are threaded into the I-beams and tightened enough to pre-load the set-screws. Tightening or loosening set-screws allows the height, slope and twist of the guide rail to be adjusted along its entire length. The set-screws and clamping bolts are easily accessible and simple to adjust.

The I-beams serve another purpose –to support the drive chain that is used to position the analyzer arm. The chain rests on the top surface of the I-beams' upper flange, just outside the guide rails. This chain is engaged by an idler pulley, a tensioner and the drive sprocket mounted below the beam. Such an arrangement is much less expensive than a rack and pinion, which would have to be specially made for this application. It also provides more precise and positive drive than would be possible with a capstan roller. Some aspects of this design are unique and are patent pending in the United States.

3. Critical Performance Testing

The critical performance parameters are summarized in the following table and in figures 3 & 4. The sphere of confusion for all axes is remarkably good, particularly over the 2-theta angle range of 0-50°. The rocking of the arm about its longitudinal axis is a critical design parameter and has been measured to be within ~10μrad over the entire angular range of the arm (-5° – 135°). The rocking of the spectrometer tower remains a problem, particularly along the direction perpendicular to the x-ray beam. This shows about 100μm deviation from the beam when the arm moves from 0 to 90 degrees, which may be due to the imperfection of the bearing at the arm's pivot and/or the C-box support. The change is, however, gradual over the arm's angular position of 0° to 90° and can be corrected by the motorized translation of the tower.

Table 1: Final Acceptance Tests of the Phase I IXS Spectrometer at BL12XU, SPring-8 (15-30 Apr. 2002)

TEST	**ITEMS**	**SPECIFICATION**	**MEASUREMENT**	**NOTE**
Functional Performance	Sphere of confusion of spectrometer tower and 3-m arm	theta/2theta/phi/chi < 50 microns	Phi circle < ± 0.5μm Chi arc < ± 3 μm Theta circle < ± 3 μm 2Theta circle (0-50°) < ±0.5 μm 2Theta circle (50-90°) < 30 μm	Measure with steel ball on Huber goniometer 1003 and a dial gauge
	Analyzer theta/chi axes intersection	within 50 microns	Needs to be done	Measure with steel ball on Huber goniometer 1003 and a dial gauge
	Angular stability of analyzer stage against arm and analyzer stage motion	within 2 arcsec or 10 microrad or 30 microns deviation at 3 meters from sample	See Fig. 4	Measure with digital levels
	Static stability of simulated measurements	within autocollimator's resolution 0.5 arcsec measured overnight	Overnight drift less than 2 arcsec. (see Fig. 3)	Measure with autocollimator

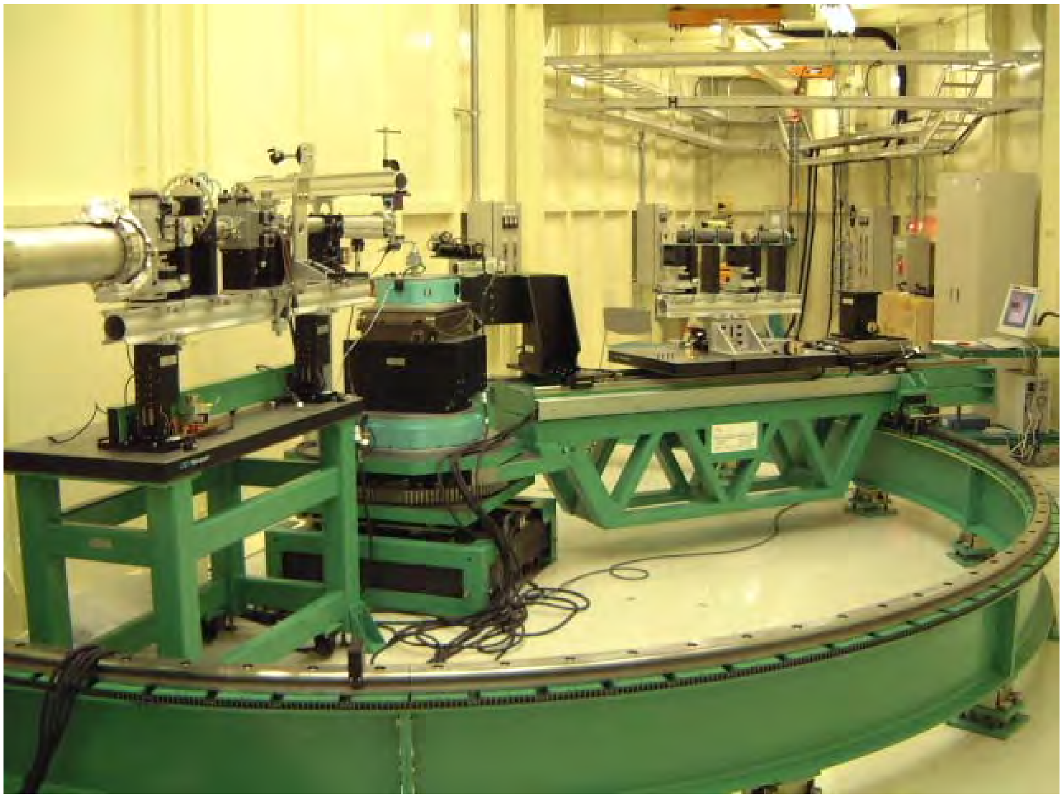


Fig.1: The IXS spectrometer installed in the experimental hutch of BL12XU

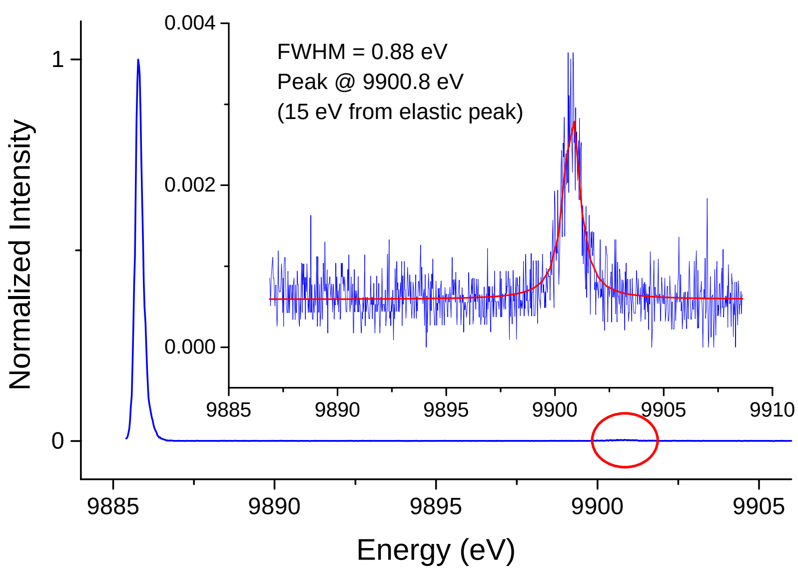
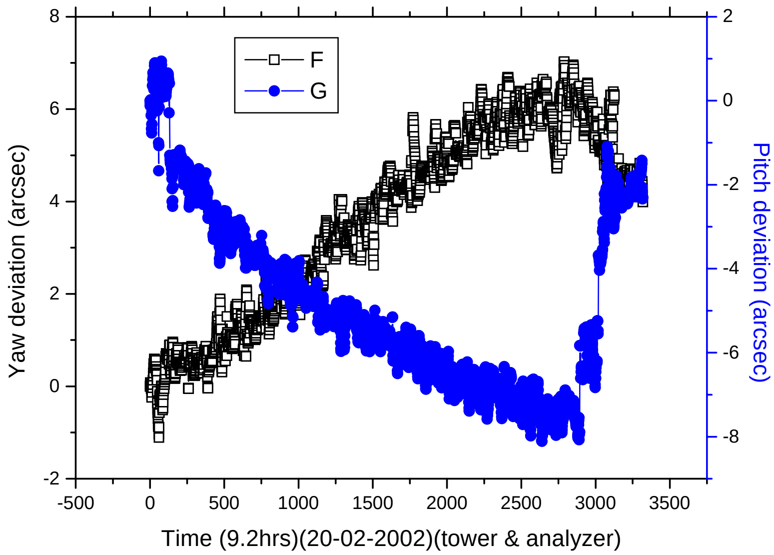


Fig.2: First IXS spectrum showing the plasmon loss feature from a 150-µm thick Al foil. Momentum transfer was 0.437 Å^{-1}. Total energy resolution was about 250 meV. Count rate on the peak of the plasmon feature was roughly 10c/sec.



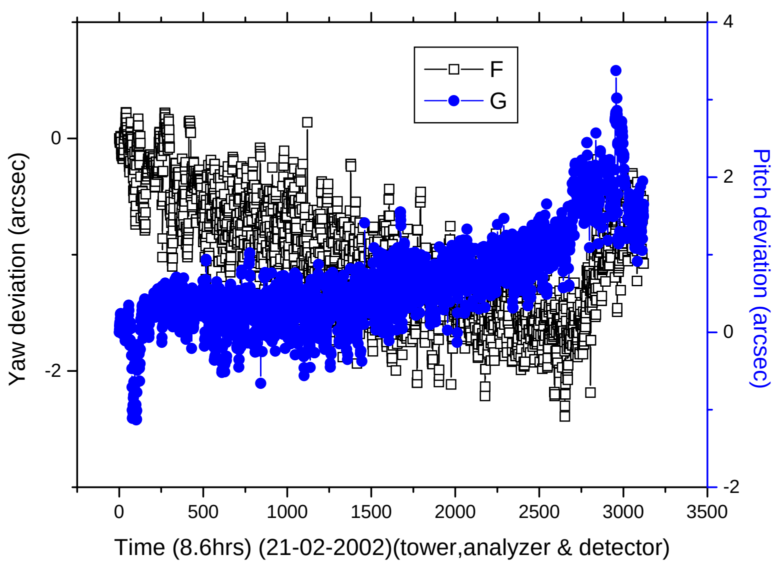
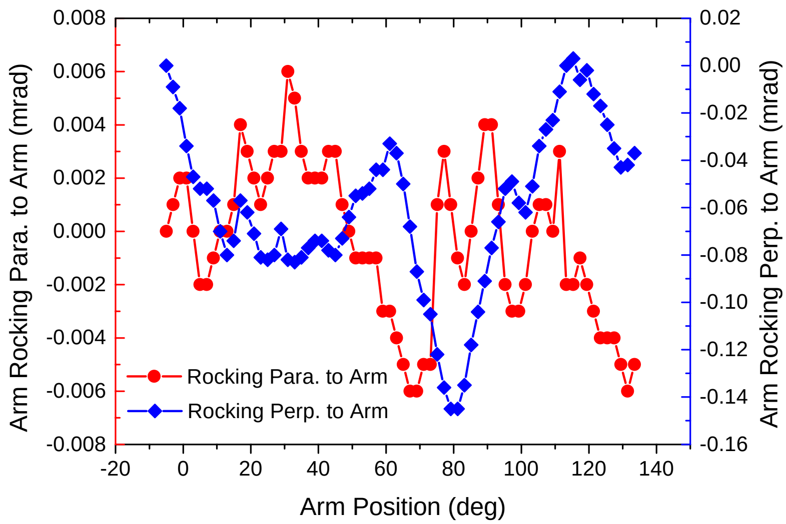


Fig. 3: Static stability of the spectrometer measured overnight using an autocollimator mounted on the spectrometer tower reflecting mirrors mounted on the analyzer and detector stages, respectively. All movable parts were locked properly in the second measurements.



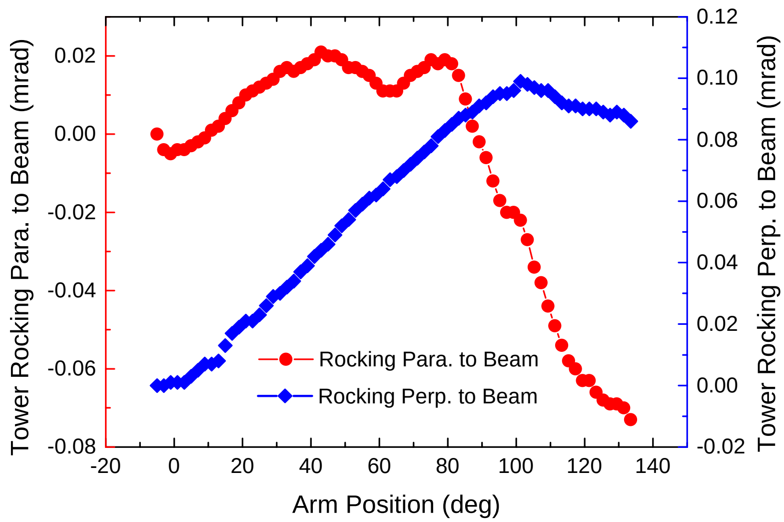


Fig. 4. Rocking of the 3-m arm and the spectrometer tower with respect to the arm position measured using two-dimensional Nivel 20 electronic levels positioned on the analyzer stage and the tower, respectively